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Energy Efficiency
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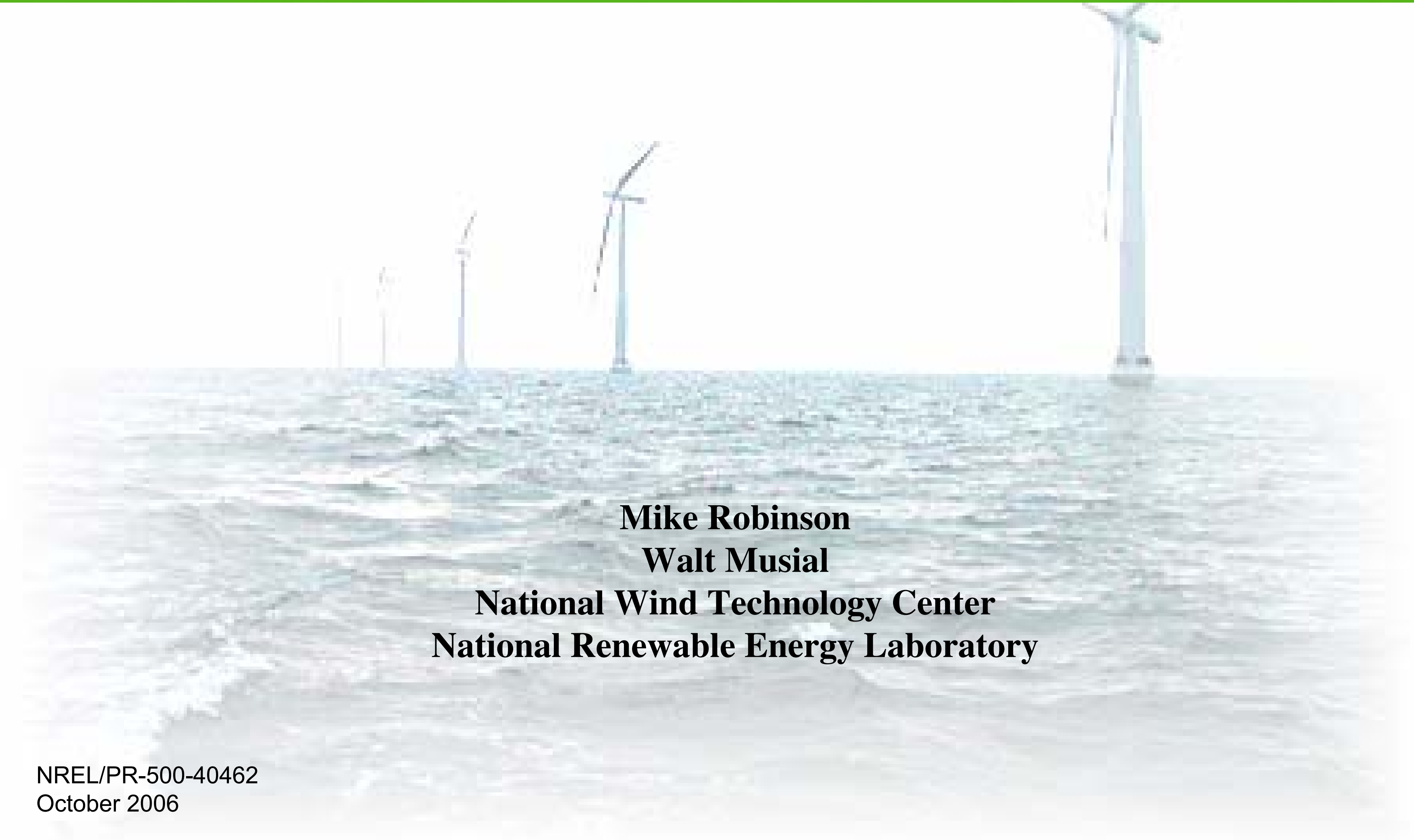
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Offshore Wind Technology Overview



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National Wind Technology Center
National Renewable Energy Laboratory

NREL/PR-500-40462
October 2006

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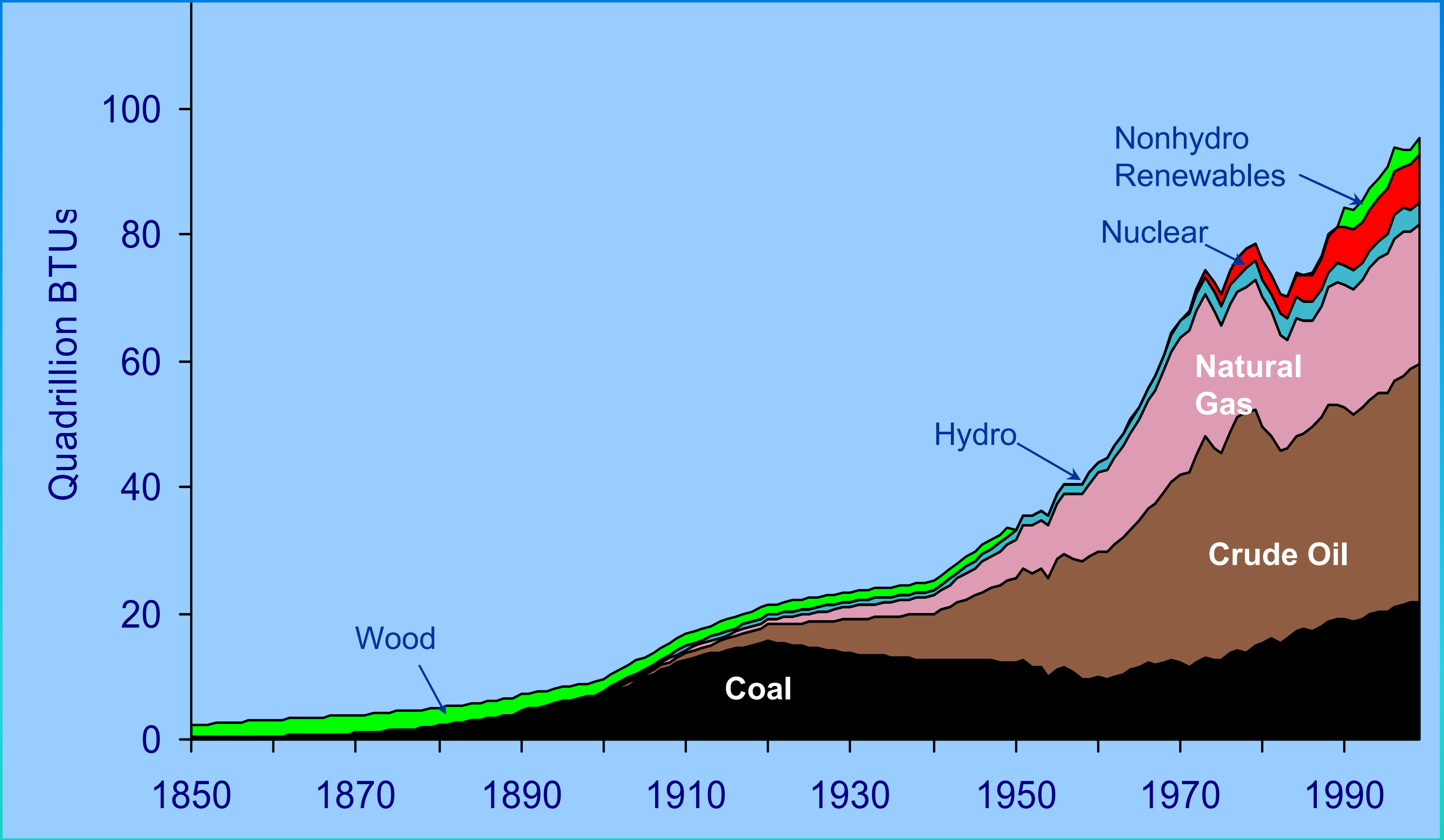
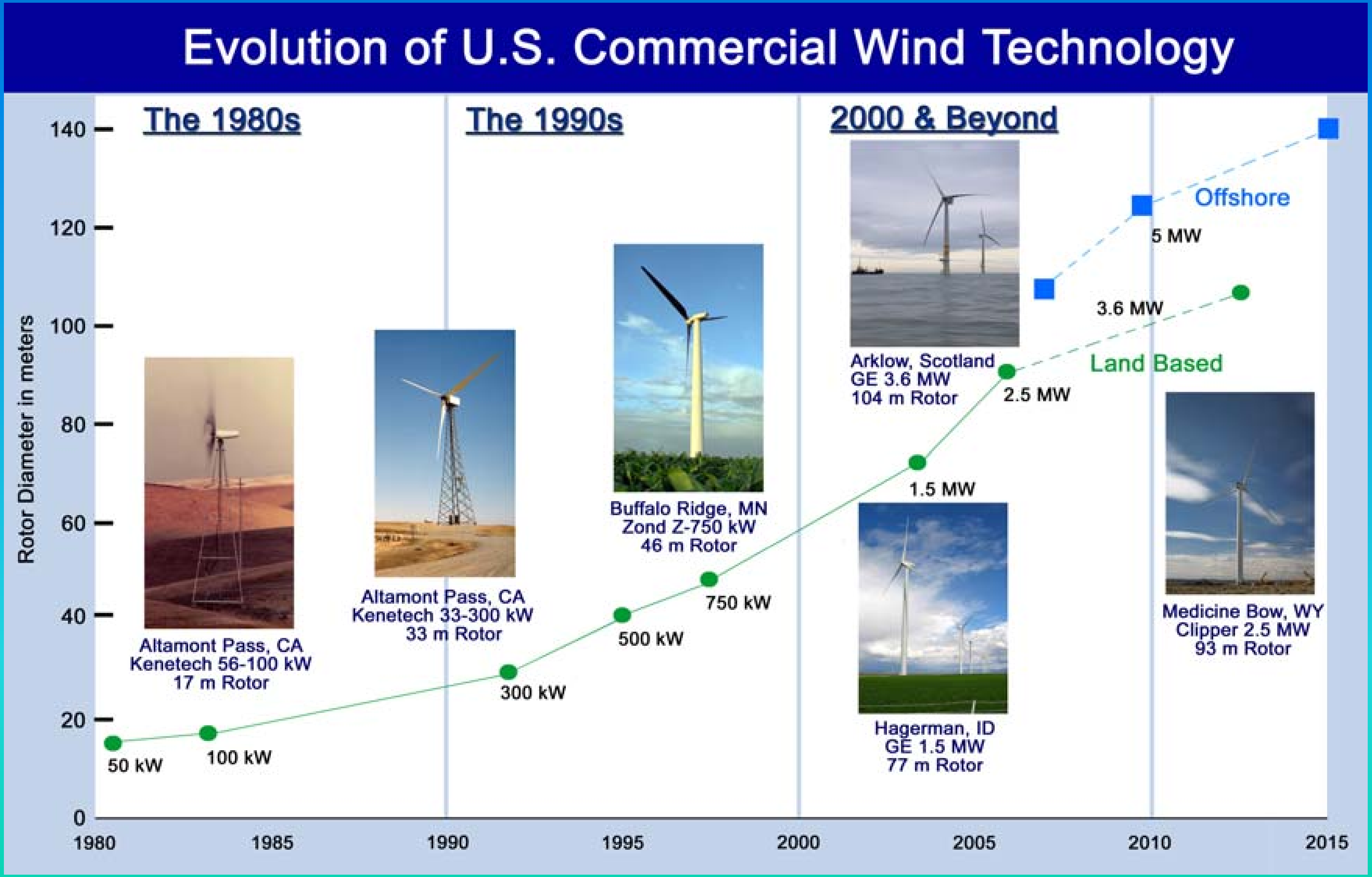
The U.S. Energy Picture by Source - 1850-1999



Source: 1850-1949, Energy Perspectives: A Presentation of Major Energy and Energy-Related Data, U.S. Department of the Interior, 1975; 1950-1996, Annual Energy Review 1996, Table 1.3. Note: Between 1950 and 1990, there was no reporting of non-utility use of renewables. 1997-1999, Annual Energy Review 1999, Table F1b.

Evolution of U.S. Commercial Wind Technology



Offshore GE Wind Energy 3.6 MW Prototype

- Offshore GE 3.6 MW
  104 meter rotor diameter
- Offshore design requirements considered from the outset:
  - Crane system for all components
  - Simplified installation
  - Helicopter platform

Cost of Energy Trends

1981: 40 cents/kWh

- Increased Turbine Size
- R&D Advances
- Manufacturing Improvements

2006: 9.5 cents/kWh

- Multimegawatt Turbines
- High Reliability Systems
- Infrastructure Improvements

Land-based

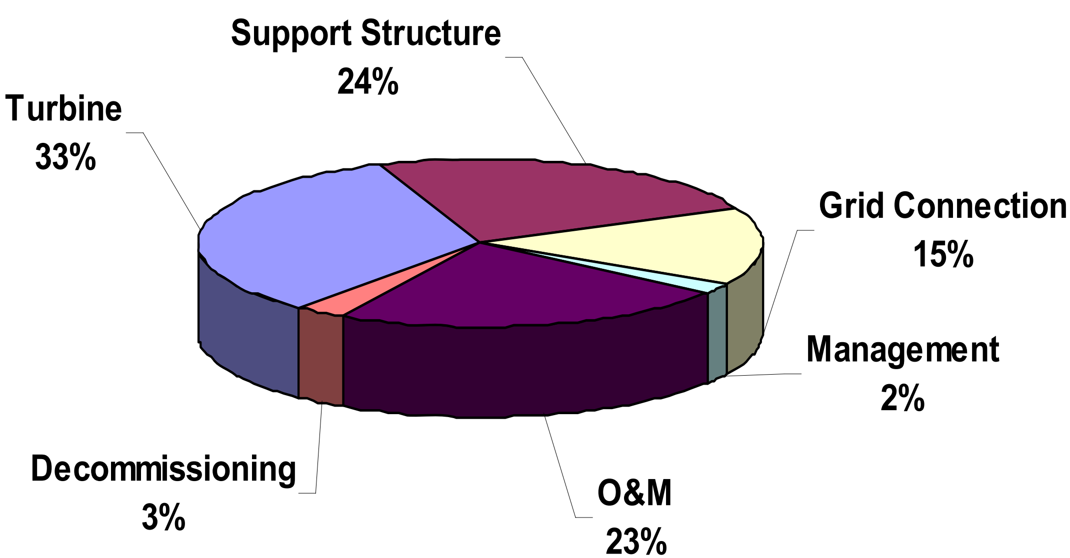
2006: 3 - 6 cents/kWh

Offshore

2014: 5 cents/kWh

Offshore Turbine Size Drivers

- Offshore Turbines are about 1/3 of total project cost.
- Thus, as turbines grow larger:
  - Foundation costs decrease
  - Electrical infrastructure costs decrease
  - Operational expenses decrease
  - More energy is generated per area.
- Offshore infrastructure is also suited for larger machines.



Offshore Wind - Life Cycle Cost of Energy

GE Wind

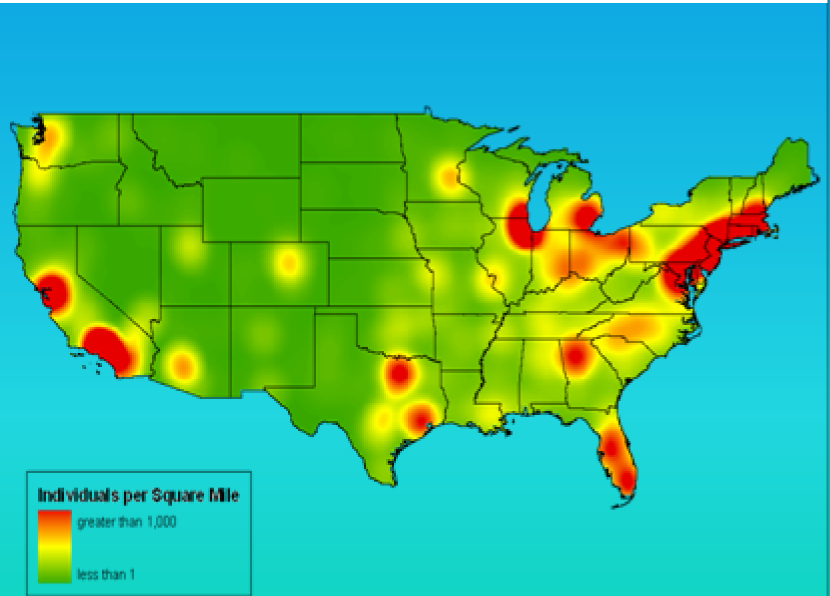
Offshore Wind – U.S. Rationale
Why Go Offshore?

Windy onshore sites are not close to coastal load centers

The electric utility grid cannot be easily set up for interstate electric transmission

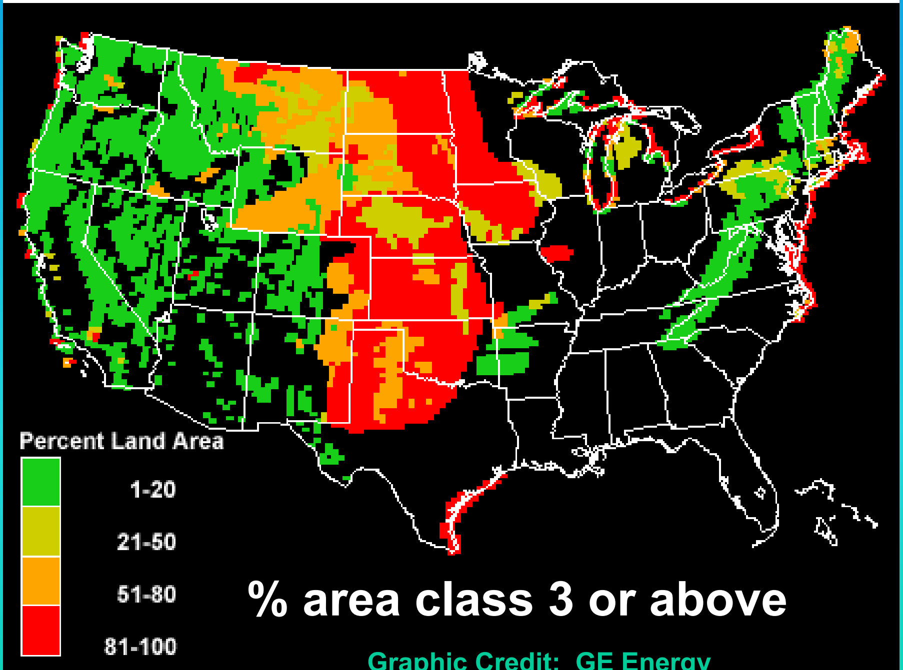
Load centers are close to the offshore wind sites

US Population Concentration



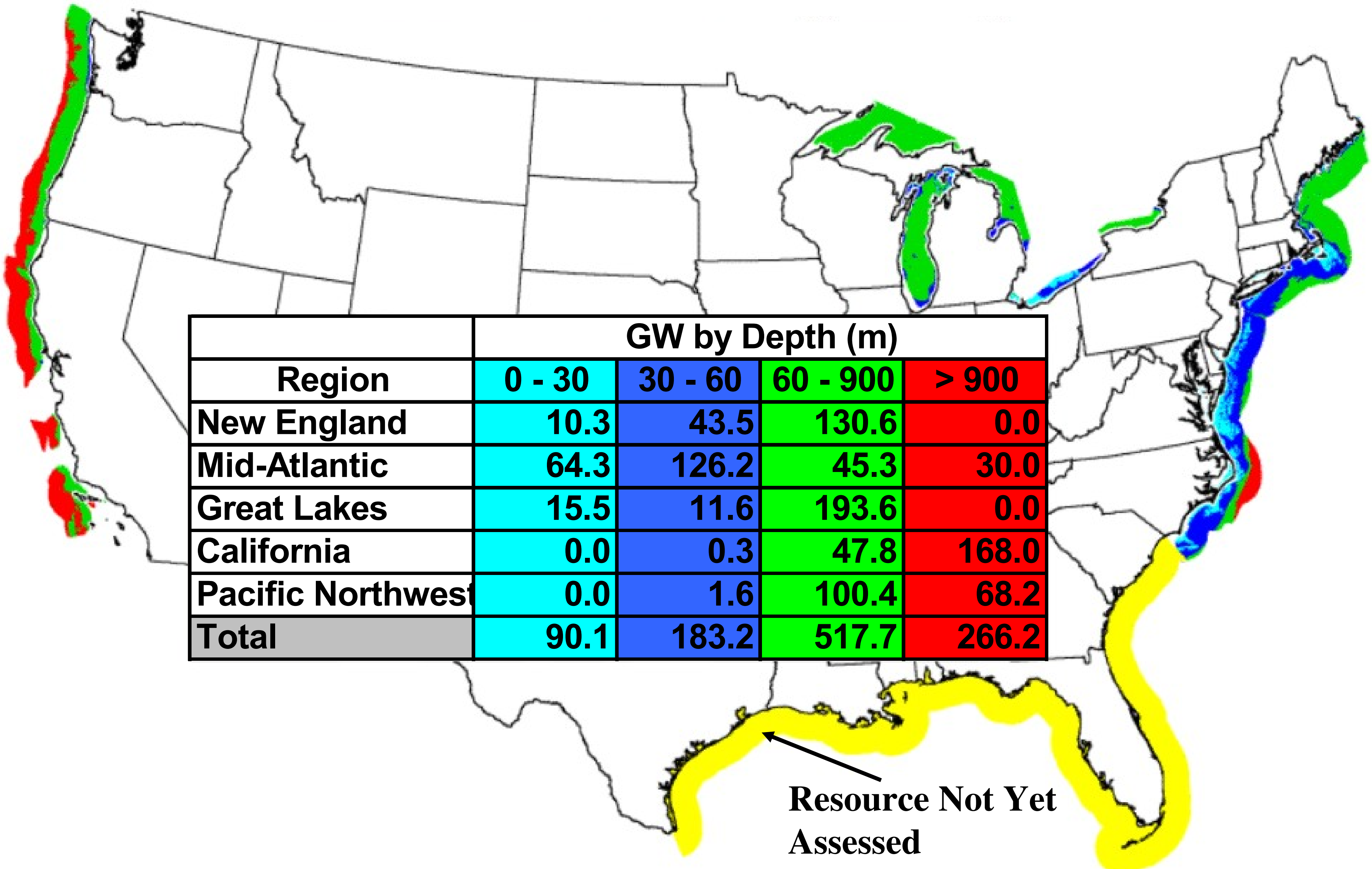
Graphic Credit: Bruce Bailey AWS Truewind

US Wind Resource



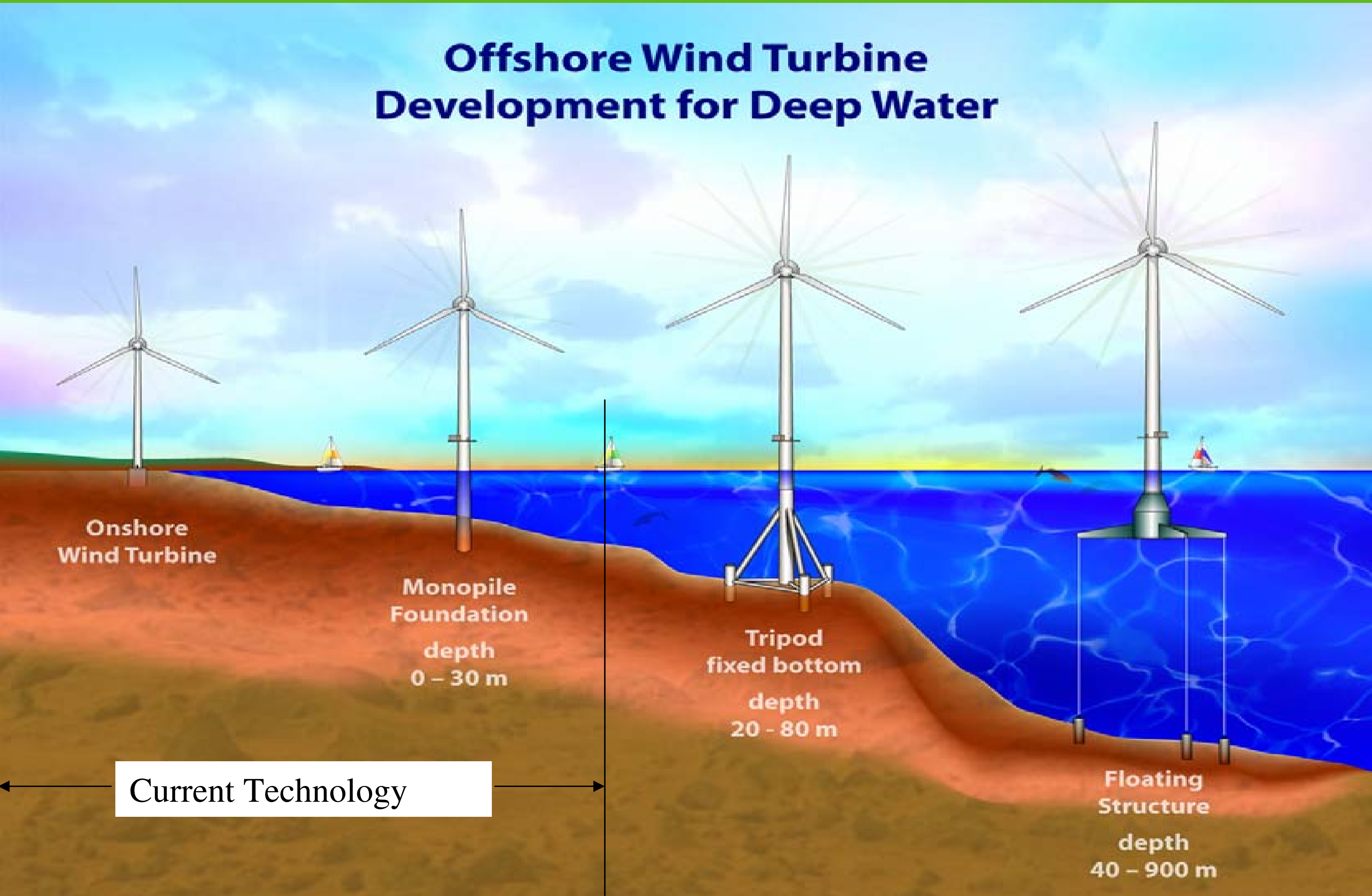
Graphic Credit: GE Energy

U.S. Offshore Wind Energy Resource



	GW by Depth (m)			
Region	0 - 30	30 - 60	60 - 900	> 900
New England	10.3	43.5	130.6	0.0
Mid-Atlantic	64.3	126.2	45.3	30.0
Great Lakes	15.5	11.6	193.6	0.0
California	0.0	0.3	47.8	168.0
Pacific Northwest	0.0	1.6	100.4	68.2
Total	90.1	183.2	517.7	266.2

Offshore Wind Turbine Development



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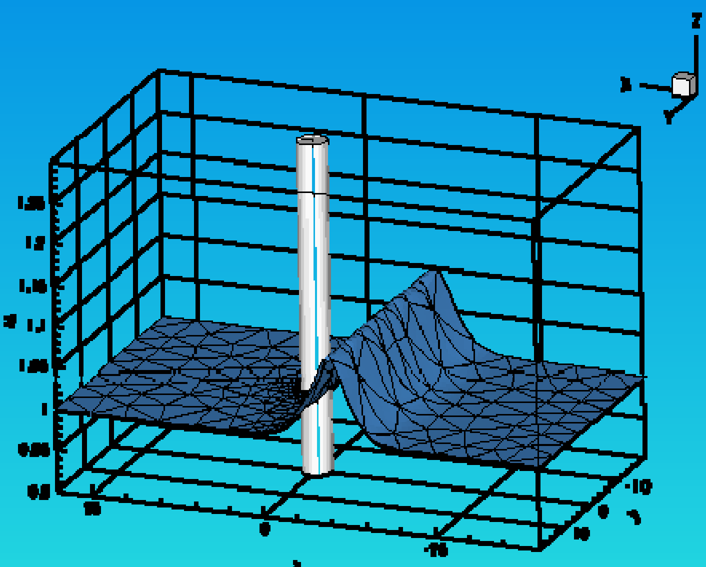
Arklow Banks Windfarm
The Irish Sea



R. Thresher

Fixed Bottom Substructure Technology

Proven Designs

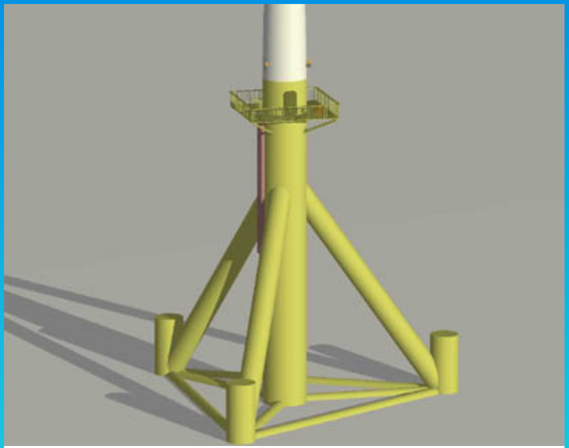
Monopile Foundation

- Most Common Type
- Minimal Footprint
- Depth Limit 25 m
- Low stiffness

Gravity Foundation

- Larger Footprint
- Depth Limit?
- Stiffer but heavy

Future



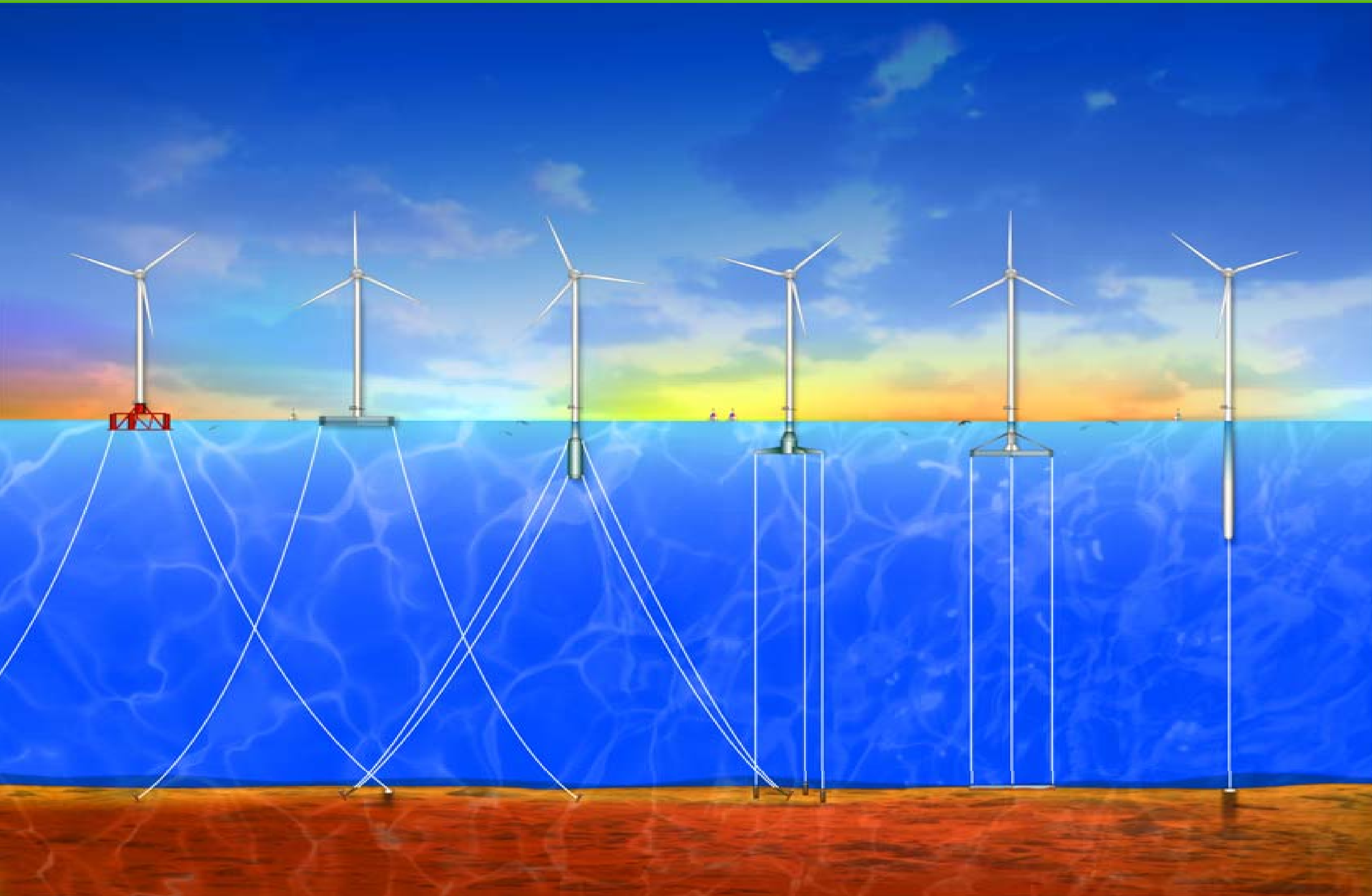
Tripod/Truss Foundation

- No wind experience
- Oil and gas to 450 m
- Larger footprint

Graphics source: http://www.offshorewindenergy.org/

Transitional Depth Foundations 30-m to 90-m Depths??

Floating Foundations >60-m Depths



Location of Existing Offshore Installations Worldwide

Source: Wind Directions, September 2004

Enercon 4.5-MW Offshore Prototype

Enercon 4.5MW 112 meter rotor

440 metric tonnes

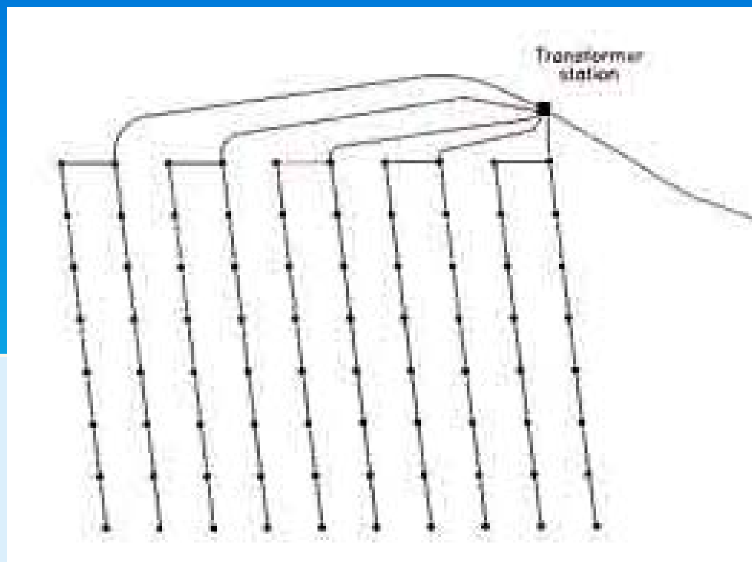
RePower 5-MW – World's Largest Turbine

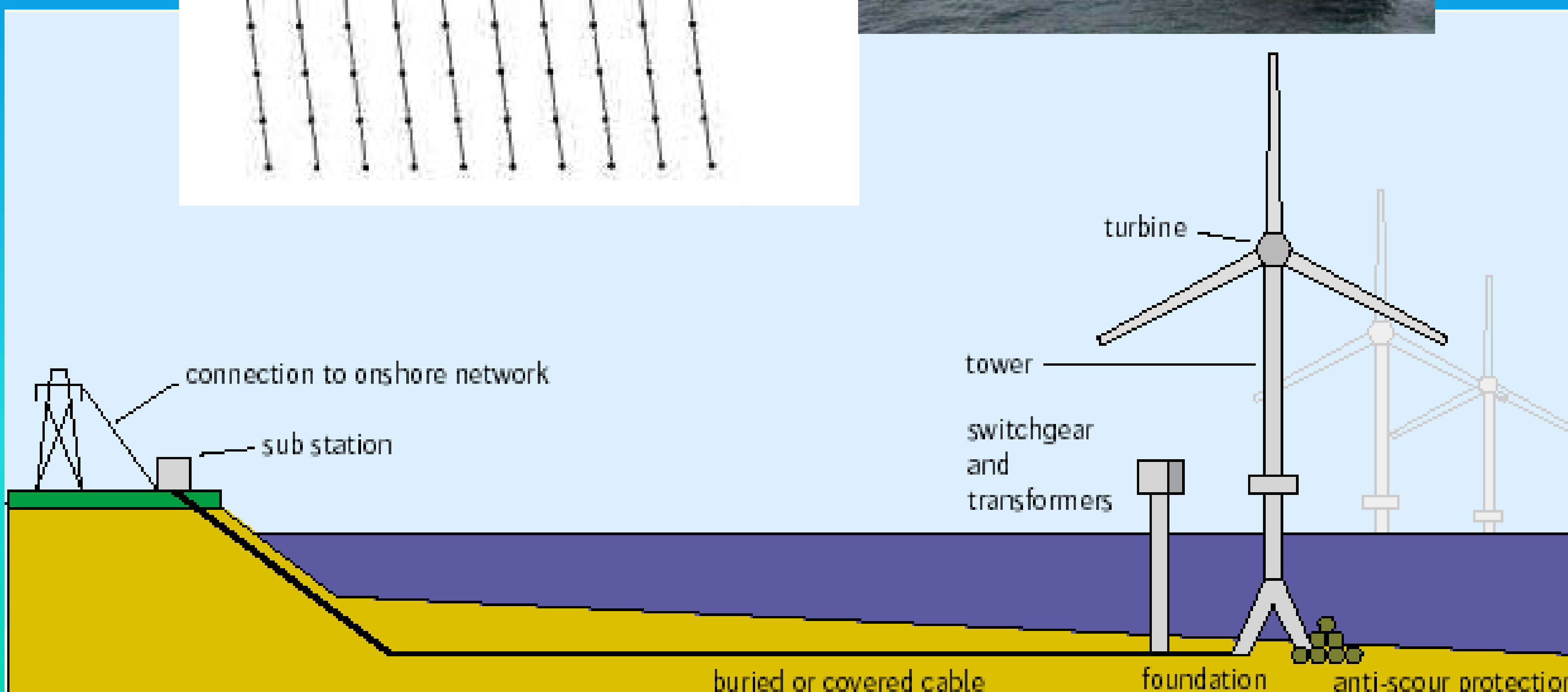

RePower


RePower

- 5-MW Rating
- 61.5-m blade length (LM Glasfibres)
- Offshore Demonstration project by Talisman Energy in Beatrice Fields
  - 45-m Water Depths
  - Two machines

Typical Offshore Wind Farm Layout





Horns Rev

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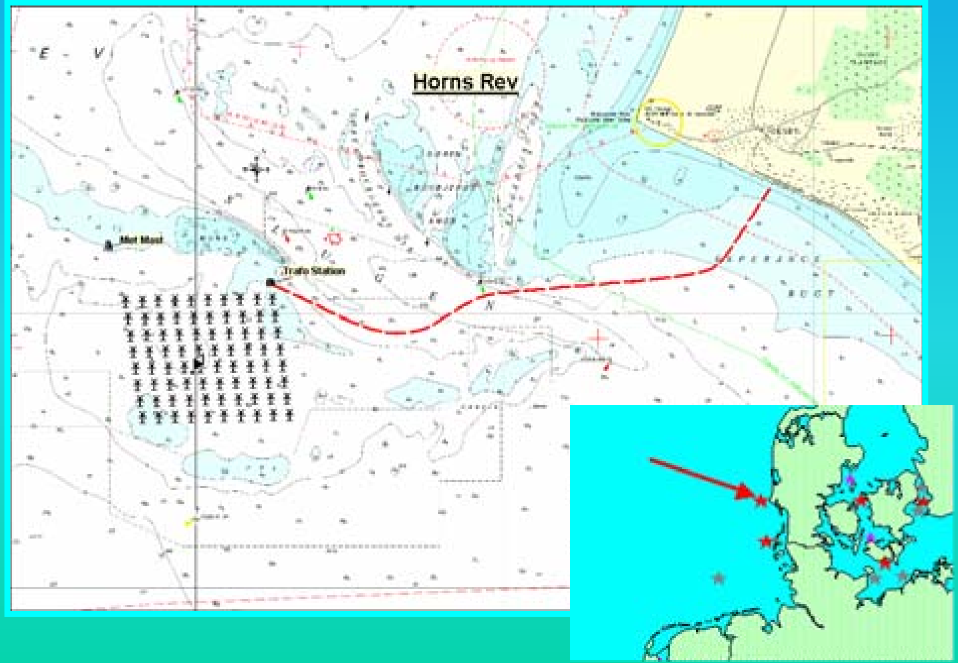
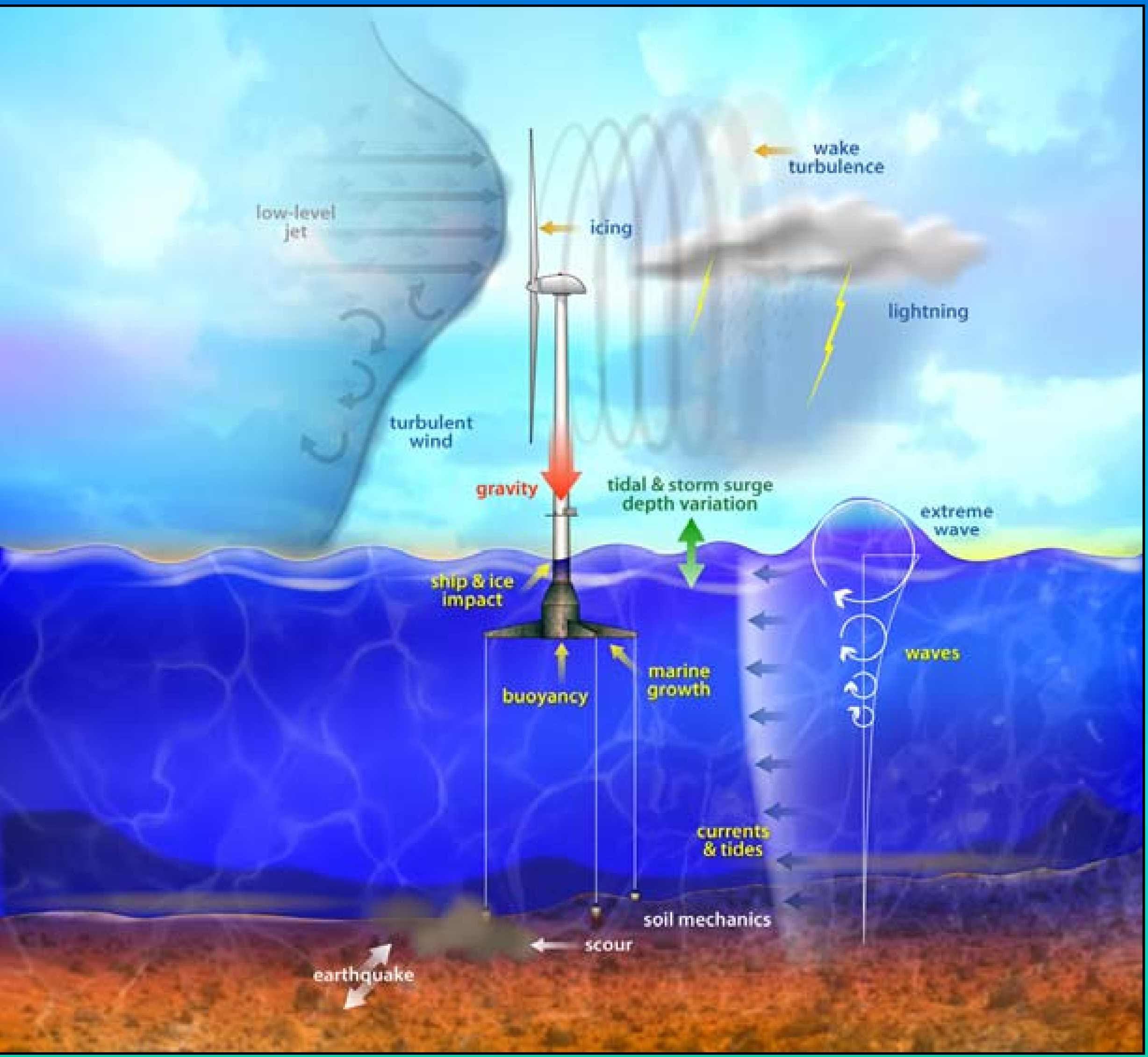
Horns Rev Wind Farm - Denmark

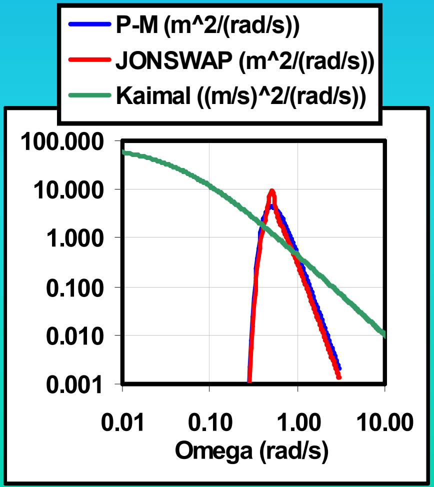
Country: Denmark
Location: West Coast
Total Capacity: 160 MW
Number of Turbines: 80
Distance to Shore: 14-20 km
Depth: 6-12 m
Capital Costs: 270 million Euro
Manufacturer: Vestas
Total Capacity: 2 MW
Turbine-type: V80 – 80-m diameter
Hub-height: 70 m
Mean Windspeed: 9.7 m/s
Annual Energy output: 600 GWh



Offshore Technical Challenges



- Turbulent winds
- Irregular waves
- Gravity / inertia
- Aerodynamics:
  - induction
  - skewed wake
  - dynamic stall
- Hydrodynamics:
  - scattering
  - radiation
  - hydrostatics
- Elasticity
- Mooring dynamics
- Control system
- Fully coupled cx



Wind and Wave Spectra

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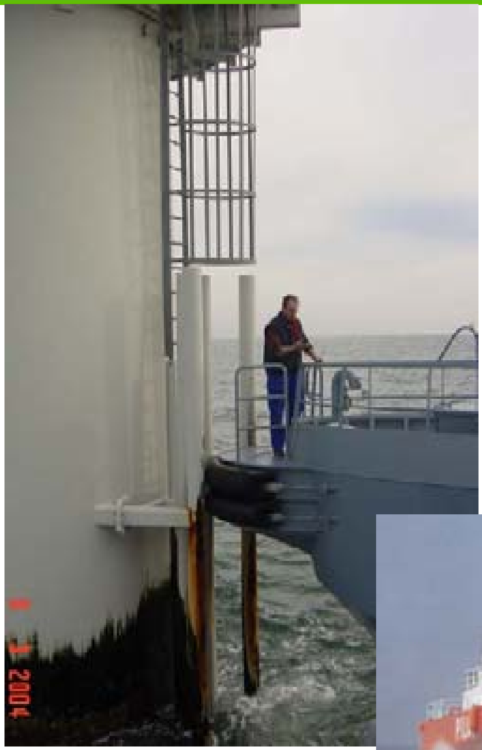
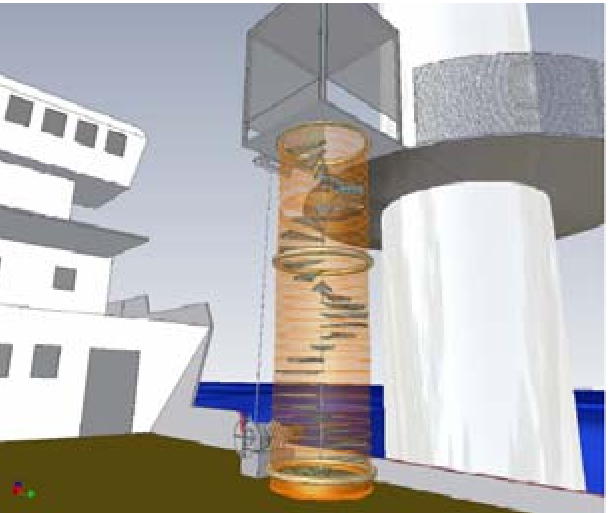
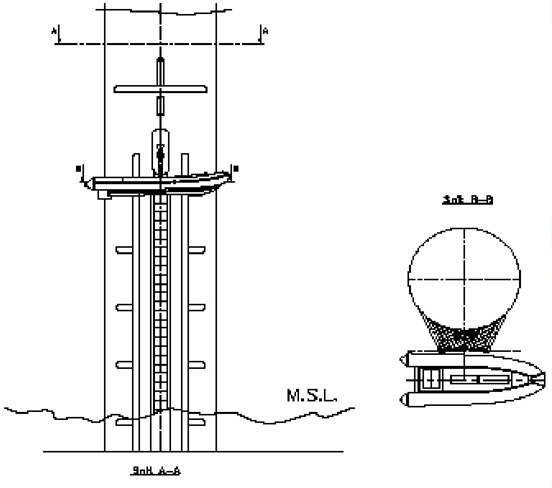
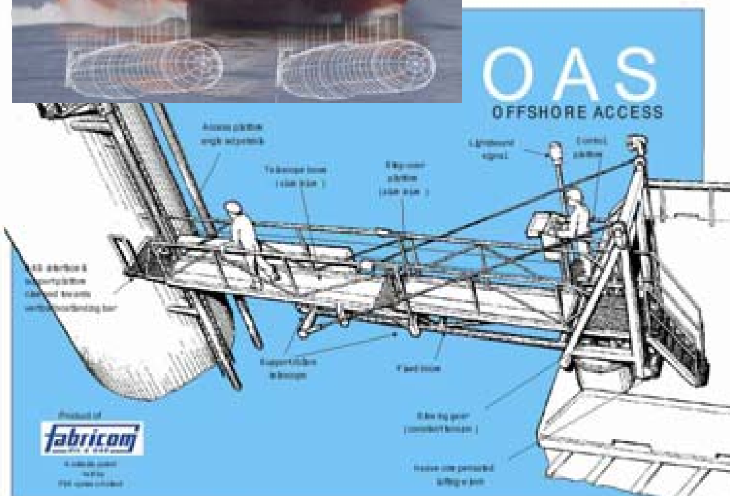
Offshore Turbine Access

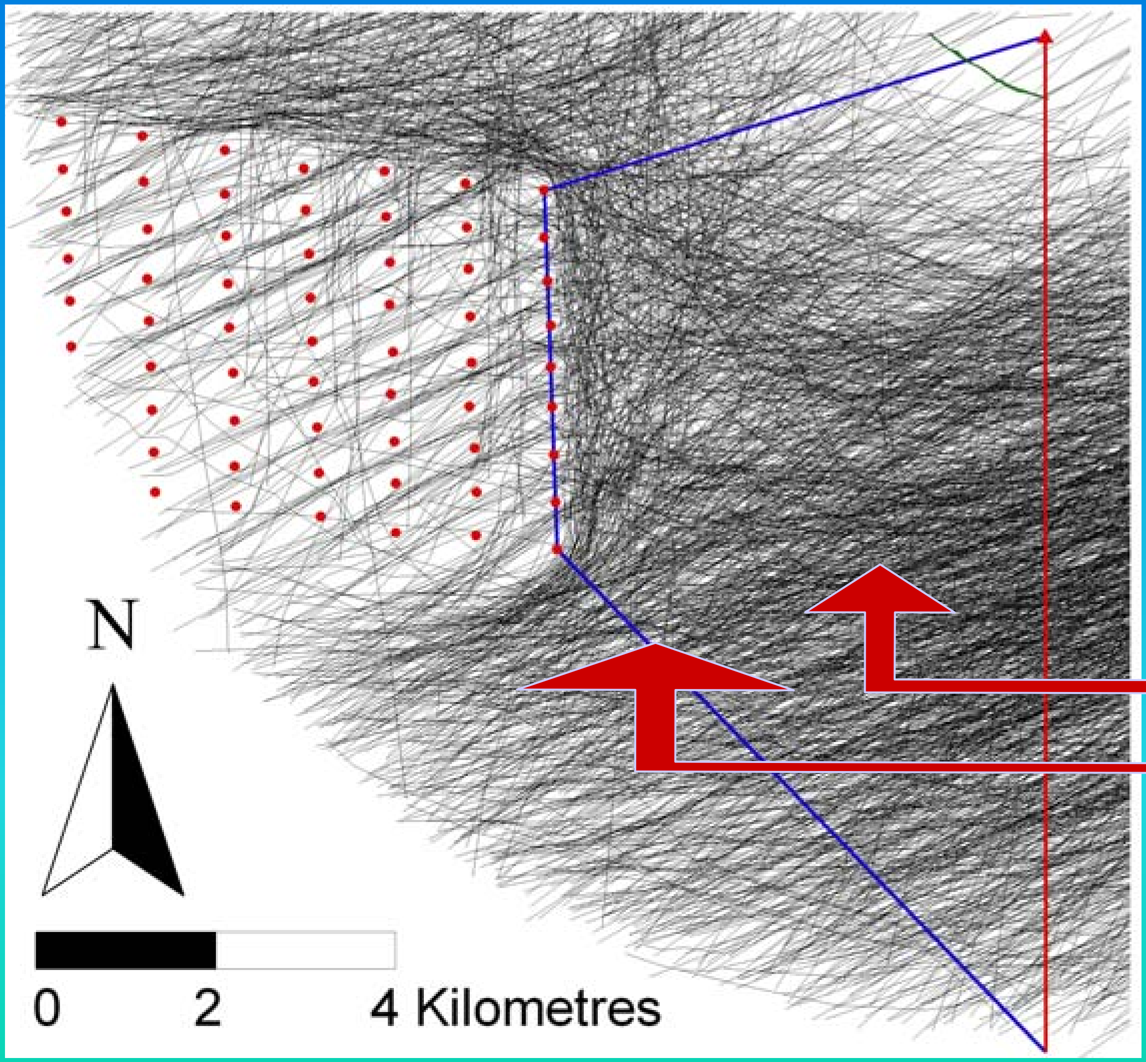








Radar Images of Migrating Birds at Nysted Wind Power Plant - Denmark



Operation (2003):

Birds perceive the presence of wind turbines even in bad visibility

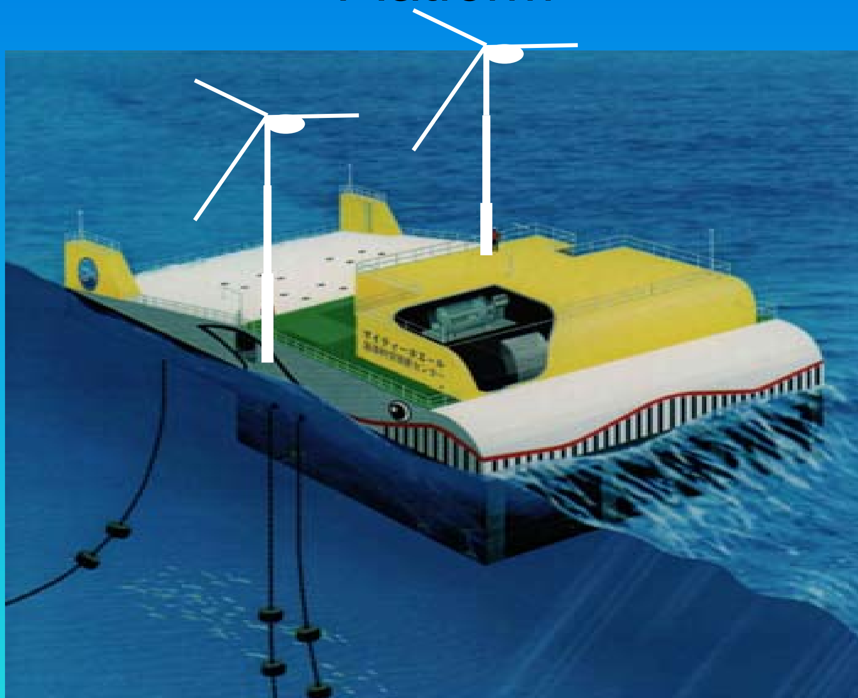
Response distance:

day = c. 3000 m

night = c. 1000 m

Offshore Wind / Wave Synergy

Small Wind-OWC Wave Platform



- **Common Engineering & Design Considerations**
- **Maximize Grid Interconnect Potential Through Dual Technologies**
- **Improve Intermittency & Total Energy Output**
- **Increase System Reliability & Reduce Maintenance**

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EPRI Building a Coalition of Developers, Universities and Other Stakeholders to Explore the Wind / Wave Development Potential

A Future Vision for Wind Energy Markets

Tomorrow

Today 2005

Bulk Power Generator
4-6¢ at 15 mph

- Land Based
- Bulk Electricity
- Wind Farms

Potential 20% of Electricity Market

Land Based Electricity Path

Land Based LWST Large-Scale 2–5 MW

Transmission Barriers

LWST Turbines:
- 3¢/kWh at 13 mph
- Electricity Market

2012

Offshore Electricity Path

Offshore Turbines 5 MW and Larger

Cost & Regulatory Barriers

Offshore LWST Turbine:
- 5 Cents/kWh
- Shallow/***Deep*** *Water*
- Electricity Market
- Higher Wind Sites

2012 and Beyond

Advanced Applications Path

Land or Sea Based:
- **Hydrogen**
- **Clean Water**

Cost & Infrastructure Barriers

Custom Turbines:
- Electricity
- H2 Production
- Desalinate Water
- Storage
- Multi-Market

2030 and Beyond